

1 COLOR-CALIBRATION SENSOR SYSTEM
2 FOR INCREMENTAL PRINTING
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5 RELATED PATENT DOCUMENTS
6

7 Closely related documents are other, coowned and
8 copending U. S. utility-patent applications filed in the
9 United States Patent and Trademark Office and hereby
10 incorporated by reference in their entirety into this
11 document. One is in the names of Otto Sievert et al.,
12 Serial 08/625,422 entitled "SYSTEMS AND METHOD FOR ESTAB-
13 LISHING POSITIONAL ACCURACY IN TWO DIMENSIONS BASED ON A
14 SENSOR SCAN IN ONE DIMENSION" and issued as U. S. Patent
15 5,____,____; another in the names of Gregory D. Nelson et
16 al., 08/636,439 entitled "SYSTEMS AND METHOD FOR DETERMIN-
17 ING PRESENCE OF INKS THAT ARE INVISIBLE TO SENSING DE-
18 VICES", and issued as U. S. Patent 5,____,____; yet an-
19 other in the name of Jack H. Schmidt, 08/665,777, "SWATH
20 SCANNING SYSTEM USING A REFLECTING IMAGER", and issued as
21 U. S. Patent 5,____,____; yet another in the names of
22 Robert Haselby et al., 08/717,921 for "UNDERPULSED SCANNER
23 WITH VARIABLE SCAN SPEED, P. W. M. COLOR BALANCE, SCAN
24 MODE", and issued as U. S. Patent 5,____,____; a further
25 one in the names of Chris T. Armijo et al., 08/811,412,
26 "DETECTION OF PRINTHEAD NOZZLE FUNCTIONALITY BY OPTICAL
27 SCANNING OF A TEST PATTERN", and now issued as U. S. Pat-
28 ent 5,____,____; still another in the names of Francis
29 Bockman et al., 08/960,766, "CONSTRUCTING DEVICE-STATE
30 TABLES FOR INKJET PRINTING", and issued as U. S. Patent
31 5,____,____; and yet another in the name of Ramon Borrell,
32 09/146,858, "ENVIRONMENTAL AND OPERATIONAL COLOR CALIBRA-

1 TION, WITH INTEGRATED INK LIMITING, IN INCREMENTAL PRINT-
2 ING", and issued as U. S. Patent 5,____,____.
3
4

5 FIELD OF THE INVENTION
6

7 This invention relates generally to machines and
8 procedures for incremental printing or copying of text or
9 graphics on printing media such as paper, transparency
10 stock, or other glossy media; and more particularly to a
11 machine and method that ^{constructs} construct — under direct computer
12 control — text or images from individual colorant spots
13 created on a printing medium, in a two-dimensional pixel
14 array. For purposes of this document, by the phrases
15 "incremental printing" and "incremental printer" it is
16 meant to encompass all printers and copiers that perform
17 computer-controlled construction of images by small
18 increments.

19 Incremental printers thereby form images either di-
20 rectly on the print medium — as in the case of inkjet,
21 dot-matrix or wax-transfer systems — or on an electro-
22 statically charged drum just before transfer to the medium
23 as in the case of laser printers. Thus by "incremental
24 printer" it is meant to exclude printing presses, which
25 form a whole image from a previously prepared master neg-
26 ative or plate. The invention relates most particularly
27 to hardware for use in calibration to optimize color
28 effects, prevent overinking, and perform other functions
29 directly related to image quality.
30
31

1 BACKGROUND OF THE INVENTION

2
3 1. INTRODUCTION

4
5 Printer users have a need for accurate color repro-
6 duction, for a very great variety of reasons. Many busi-
7 nesses depend on color for their image recognition and
8 identification. Even the optimum maintenance of trademark
9 rights in some situations can depend upon accurate presen-
10 tation of the color portions of a mark.

11 Much more familiar motivations include the desire of
12 hobby and home users to see natural flesh tones in printed
13 reproductions of photographs, and to see colors in graphic
14 designs that match their originals.

15 Colors machine-printed as arrays of ink dots are
16 affected by a wide range of factors including temperature,
17 humidity, ink viscosity, absorption by paper or other
18 printing media, writing-mechanism wear, and many others.
19 All these factors cause variation in inkdrop volume and
20 thereby dot size on the media.

21
22 Efforts to analyze such factors and take them into
23 account typically center about optical measurements of one
24 type or another. These may be made at the factory for a
25 complete line of printers, or made in the field for a sin-
26 gle production unit — or skilfully devised combinations
27 of these alternatives.

28 United States Patent 5,537,516 of Sherman et al. of-
29 fers (columns 2 and 3) a brief but helpful orientation as
30 to the differences between measurements respectively made
31 with a densitometer, a colorimeter and a scanner. Sherman
32 also offers several proposals for using a scanner to
33 calibrate a printer.

1 These proposals include various regimes of combined
2 factory and field measurements, linked through specially
3 constructed standard or customized target test patterns.
4 Sherman also teaches defocusing or diffusing the targets
5 to minimize adverse characteristics of scanners.

6 Although color accuracy of chromatic colors is of
7 enormous importance commercially, for purposes of the
8 present document (including the claims) the word "color"
9 is used to encompass both chromatic and nonchromatic
10 colors. Similarly the term "colorant" is used to encom-
11 pass both chromatic and nonchromatic colorants.

12 General phrases such as "color measurement" are used
13 to encompass both densitometry and colorimetry. In par-
14 ticular they encompass measurement of exclusively non-
15 chromatic colors, as well as measurement of chromatic
16 colors either alone or mixed with nonchromatic colors.

17 U. S. 5,272,518 of Vincent, assigned to the Hewlett
18 Packard Company, describes a small handheld colorimeter
19 for use in calibrating incremental printers and other im-
20 age-related devices associated with computers. To exclude
21 ambient light the device includes a hood that is meant to
22 be manually brought down directly against a calibration
23 test pattern.

24 Vincent at one point may seem to suggest too that a
25 colorimeter such as his invention may be incorporated into
26 the printer or other device to facilitate autocalibration;
27 however, Vincent does not teach how to implement any such
28 suggestion. In addition, Vincent teaches extensively the
29 theoretical foundations of calibration for image-related
30 devices of the type under consideration here.

31 It is known in handheld colorimeters and the like to
32 use a gas-arc flashlamp, particularly for the benefits of
33 the broad, relatively flat and somewhat controllable spec-

1 tral emission of such a lamp. Neither the Vincent system,
2 however, nor any known system of light measurement used in
3 a printer, employs such a lamp.

6 2. DENSITOMETRY

8 For a given set of inks with known spectral values
9 and a known printing medium, one can calculate a color
10 table that maps a desired color in some color space into a
11 set of values to be printed on the media. These values
12 may be given as a percentage of the medium to cover with
13 each of the inks.

14 A color table is created for each unique combination
15 of ink and printing medium. To compensate for dot-size
16 variation, the color table should be adjusted or calibra-
17 ted for the current operating conditions.

18 One way to accomplish this is through a density mea-
19 surement for each of the inks used, by first printing a
20 series of swatches at various nominal (intended) densi-
21 ties, then measuring the actual density of the samples.
22 What is measured is the fraction of the medium that is
23 covered by the dots, and in most densitometer methodolo-
24 gies the actual color does not matter.

25 This process depends on the composition of the ink
26 remaining constant, and likewise the spectral character-
27 istics of the medium. Typically these tables are computed
28 during development of a printer, and stored permanently in
29 the printer — where they can be changed only by replacing
30 the software storage component, typically a read-only mem-
31 ory (ROM) circuit board.

32 Through proper use of such measurements, it is possi-
33 ble to compensate for all the factors that affect dot size

1 — thus making the color output of the printer more con-
2 sistent — but the calibration is valid only for a current
3 set of environmental conditions, inks and media. A change
4 in temperature therefore would require a new calibration.

5 Later calibration is not possible with a different
6 medium for which no color table exists. Also it is as-
7 sumed that the colors do not interact — each ink is lin-
8 earized independently of the others, in a one-dimensional
9 calibration.

10 11 12 3. COLORIMETRY

13
14 To extend the calibration process to be more general,
15 it is necessary to measure actual spectral values of ink
16 at different levels of coverage on the desired medium.
17 ~~This accounts for interaction of inks and media, and makes~~
18 the process independent of foreknowledge of ink and medium
19 spectral characteristics.

20 In this process there is an interaction between the
21 ink colors, because of the overlap between the spectra of
22 the different inks. Although an ink is treated as con-
23 tributing color in a single spectral band, essentially
24 every ink actually has components in more than one part of
25 the spectrum.

26 This is a multidimensional calibration. This process
27 creates custom color tables for current ambient conditions
28 and arbitrary ink and media. In addition, such measure-
29 ments in effect linearize the first type of calibration
30 mentioned above.

31
32

1 4. METHODS

2
3 At least two methodologies are known heretofore for
4 calibration of incremental color printers:
5

6 (a) Off-line calibration — In this approach a user
7 operates a spectrally discriminating optical sensing
8 device, i. e. a colorimeter, to make measurements of a
9 test pattern. The colorimeter readings are taken inde-
10 pendently of the printer operation.

11 First the printer must be used to print the test
12 pattern onto the desired medium. Modernly this process is
13 controlled by an application program in a host computer or
14 in an onboard microprocessor that is part of the printer
15 itself. The pattern usually includes many color patches,
16 typically between fifty and several hundred.

17 ~~Then the user must operate a colorimeter — such as~~
18 ~~for example a small unit sometimes called a "color mouse".~~
19 ~~(The term "color mouse" appears to be related to, but not~~
20 ~~one of, the trademarks of the Color Savvy Company.)~~

21 Alternatively the user may use a spectrophotometer.
22 In either case, the equipment is used to measure the pat-
23 ches one by one while the readings are processed by the
24 application program. The application in turn creates a
25 custom color table for the instant set of conditions.

26 The application then can send accurate color values
27 to the printer (which should not modify them). If the
28 temperature or another condition changes, then the cali-
29 bration should be done again.

30 Problems with this method include the amount of time
31 required of the user to carry out a tedious process, and
32 the likelihood of error. For example, the user may place

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1 the sensor over a patch other than the one expected by the
2 system.

3 Data obtained are ordinarily exterior to the printer
4 and require use of an external processor, though the data
5 may be downloaded to the printer if the system is so con-
6 figured. (Another issue in some parts of the world is the
7 physical space required to put down a print sample with
8 swatches on a level surface for measurement.)
9

10 (b) Automatic on-line calibration — A second method
11 is automatic and was pioneered by the Hewlett Packard Com-
12 pany in its DesignJet® 2500CP printer. That product uses
13 a sensing element designed for other purposes (determining
14 pen alignment and pen condition) to make a rough density
15 measurement.

16 Examples of such sensing elements and their uses
17 appear in U. S. 5,600,350 of Cobbs et al. (assigned to the
18 Hewlett Packard Company) as well as the copending patent
19 documents listed earlier. In general these sensing ele-
20 ments are very rough in comparison with true densitome-
21 ters, but very slightly modified to provide some selective
22 spectral sensitivity to the several inks involved.

23 In a scanning inkjet printer such as the 2500CP, the
24 sensor is mounted on the moving carriage that holds the
25 inkjet pens. As is well known, the carriage moves the
26 pens back and forth across the printing medium to eject
27 swaths of ink droplets onto the medium, while these swaths
28 are arrayed along the length of the medium by lengthwise
29 advance of the medium, to form the image.

30 Accordingly, placement of the optical sensing element
31 on the carriage gives the sensor access to essentially the
32 same full area of the printing medium as the pens have.
33 Thus the pens can be used to print test-pattern swatches

1 on the medium, and then after the ink is thoroughly dry
2 the medium bearing the test pattern can be fed through the
3 machine again for measurement.

4 When applied to color calibration, the sensing ele-
5 ment is used to make measurements of swatches that go from
6 white (bare media) to opaque (complete ink coverage), in
7 for example eight steps. Light-emitting diodes (LEDs) are
8 used to illuminate the swatches, while a photodetector
9 reads the amount of light reflected from the swatches.

10 The LEDs are chosen so that the inks absorb the light
11 well, or in other words appear dark to the photodetector.

12 The detector is moved across the swatches with LED
13 illuminators operating, and the detector readings are re-
14 corded. The relative density of each swatch is calculated
15 and used to correct what may be called the "gain" of each
16 ink.

17 ~~Two LEDs are used — a green one for use with cyan,~~
18 ~~magenta and black inks, and a blue one for use with yel-~~
19 ~~low. This method provides a measure of feedback to keep~~
20 ~~the color of a printer relatively constant, but does not~~
21 ~~provide an absolute color specification. It requires~~
22 ~~lookup tables prepared in advance for each combination of~~
23 ~~ink and printing medium.~~

24 This method, even with its simple brightness measure-
25 ments combined with selective spectral excitation, still
26 remains something less than densitometry — in this docu-
27 ment for ease of reference it will be called "pseudodensi-
28 tometry". The use of a blue LED for detecting the yellow
29 ink is adopted merely as a means of being able to detect
30 that color of ink with anything approaching adequate sig-
31 nal-to-noise ratio.

Sub 98

Thus pseudodensitometry and does not at closely approach colorimetry. Problems with this method include these:

1) As the detector moves, it cannot touch the medium and so is held about 1.5 mm above the medium. This standoff spacing allows ambient light to enter the detector where it generates noise and makes readings uncertain.

2) Ink-aerosol particles from the printing process drift through the atmosphere above the medium and onto optical surfaces and coat those surfaces. There are two adverse effects: (a) the coating reduces the amount of light transmitted, making the measurement less sensitive, and (b) as the particles are colored they selectively distort the light which they pass through or reflect.

A fixed cover glass is used to protect the optical elements from aerosol — and when light transmission falls below acceptable levels, the user is prompted to replace the glass. In the meantime the system suffers the progressively drifting color inaccuracy just described at (b).

Historically the required replacement frequency has been about once a year. Recent data, however, suggest that somewhat more-frequent replacement is in order. With a true colorimetric system, replacement would be required significantly more often.

3) No absolute reference is used except the bare medium.

4) No colorimetric data are possible — only density.

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- 1 5) The full-ink-coverage point is not accurate. The
2 printer can only print one dot at each addressable
3 location, and in the worst case these dots do not
4 completely cover the medium. Therefore the nominal-
5 full-coverage point is not really measured with full
6 coverage, but the software has to assume that it is.
7
8 6) Color tables are available for only a few media. Ar-
9 bitrary media must be operated on a completely open-
10 loop basis.
11
12 7) Variation in sensor-to-medium distance changes the
13 calibration.
14
15

16 5. CONCLUSION

17
18 As shown above, problems of color consistency — and
19 calibration such as needed to achieve it — have continued
20 to impede achievement of uniformly excellent inkjet print-
21 ing on various industrially important printing media.
22 Neither the time-consuming and error-prone colorimetric
23 method, on the one hand, nor the automated but fundamen-
24 tally inaccurate pseudodensitometric method, on the other
25 hand, is able to provide fast, reliable, high-quality but
26 economical performance.

27 Precisely that kind of performance is essential in
28 the highly competitive field of modern incremental print-
29 ing. Thus important aspects of the technology used in the
30 field of the invention, particularly with regard to hard-
31 ware systems for use in efficient and accurate calibration
32 of printers, remain amenable to useful refinement.
33

1
2 SUMMARY OF THE DISCLOSURE
3

4 The present invention introduces such refinement.
5 Before offering a relatively rigorous introduction to the
6 invention, this text will provide some informal comments
7 that may be helpful in orientation. These remarks have
8 been reserved for the present section of this document
9 because they are in no way a part of the prior art (or
10 parallel developments) in color calibration. It is to be
11 understood that these preliminary comments are not a def-
12 inition or description of the invention.

13 As suggested in the preceding "Background" section,
14 the theory and procedures of calibration have been well-
15 elaborated in the art, but available hardware heretofore
16 has not been adequate. For an inkjet printer, a first
17 ~~step according to the present invention is to consider~~
18 installing into the printer a colorimeter, rather than
19 basically a pseudodensitometer as in method (b) above.

20 Vincent may suggest something of the sort; however,
21 like the pseudodensitometer the colorimeter must be moved
22 around to measure swatches. One question is how to ac-
23 complish that.

24 A natural start according to the present invention is
25 simply to mount a colorimeter such as Vincent's directly
26 on the scanning pen carriage, as done for the pseudodensi-
27 tometer. An obstacle arises immediately as commercially
28 available colorimeters — even the "color mouse" devices
29 — are far too bulky and heavy to be so mounted.

30 The Vincent type is greatly advanced in comparison
31 with earlier devices described in Vincent's introduction.
32 Nevertheless it is plainly not designed or suitable for
33 either installation or operation on a pen carriage.

1 A colorimeter typically requires some provision for
2 spectral selection that is better coordinated with the
3 sensitivities of the human eye than the simple ink-related
4 LED colors of the pseudodensitometer. The colorimeter
5 accordingly may have rotating filter wheels or other me-
6 chanically elaborate components that would be impractical
7 to operate on a scanning inkjet-pen carriage.

8 In this regard it is necessary to appreciate some
9 limitations of the scanning carriage. The carriage is
10 part of a multifaceted printing system that is extremely
11 well optimized for the highest possible image quality and
12 the highest possible throughput.

13 No part of that system can be significantly perturbed
14 without disturbing this delicate balance of electronics,
15 mechanics, thermodynamics, fluid dynamics, chemistry, and
16 economics. In particular the carriage must be accelerated
17 to printing speed and decelerated to a stop for each pass
18 of the printing elements across the medium.

19 The acceleration and deceleration demands naturally
20 limit the maximum mass that the carriage can bear, to
21 ensure a proper lifetime for the components of the car-
22 riage movement system. Assuming that the drive motor can
23 deliver adequate torque to accelerate and decelerate the
24 carriage to and from printing speed within the necessary
25 times and distances, a more massive carriage or components
26 on the carriage introduce more heat, stress and wear —
27 and thus a shorter life for the whole system.

28 In addition the dimensional envelope of the carriage
29 assembly is restricted by the presence of ink containers,
30 user access for replacement, replenishment or servicing of
31 those containers, drive electronics, connecting drive ca-
32 bles, and a position-encoding strip that must be threaded
33 entirely through the carriage. For all these reasons a

1 color sensor even remotely the size or mass of Vincent's,
2 for example, would be wholly impractical to mount on a
3 conventional inkjet printer carriage.

4
5 It will be understood that design of a colorimeter
6 small and lightweight enough to be suitable for such
7 mounting is a major project in itself, and relatively
8 daunting. The heart of such a new colorimeter is one
9 principal thrust of the present document, but some innova-
10 tions introduced in this document instead pursue an alter-
11 native approach without a new lightweight colorimeter.

12
13 One consideration that can be exploited to provide
14 such an alternative solution to the colorimeter problem is
15 that color calibration is performed very infrequently, in
16 comparison with the conventional movements of an inkjet
17 pen carriage. ~~One estimate is one color calibration for~~
18 each 10,000 to 30,000 printing passes.

19 This consideration suggests that placing the color
20 sensor on the carriage would add weight, bulk, stress,
21 wear and complexity which would be rarely used — and
22 therefore extremely cost-inefficient. Implementing a
23 color sensor in a different location would therefore be
24 more advantageous.

25 Still, the carriage is appealing because it provides
26 access to all the necessary parts of a test pattern and
27 already has the necessary associated components for both
28 motive forces and positional determination. The sensor
29 must be moved to each of the test-pattern patches (or the
30 patches to the sensor, or some of each).

31
32 One other type of printer subsystem has a comparably
33 very low duty cycle — namely a paper-cutter wheel that is

1 used to slice off completed drawings from a continuous
2 roll of printing medium. It is known to operate such a
3 paper cutter on a separate carriage that need not be ac-
4 celerated and decelerated dozens of times per image.

5 The separate carriage in that case is not provided
6 with its own drive cables or position-determining compo-
7 nents, but rather is coupled to the main carriage — for
8 positioning by those components already associated with
9 the main carriage. No such auxiliary carriage, however,
10 has ever been used for positioning a module or subsystem
11 that is directly related to color calibration, color
12 refinement, or indeed any other aspect of image quality.
13

14 With these introductory comments in mind, this doc-
15 ument will now continue with a more-formal presentation of
16 certain aspects of the invention.
17

18 In its preferred embodiments, the present invention
19 has several aspects or facets that can be used independ-
20 ently. With limited exceptions that will shortly become
21 clear, the several facets are preferably employed together
22 to optimize their benefits.
23

24 In preferred embodiments of a first of its facets or
25 aspects, the invention is an incremental printer for
26 forming desired images on a printing medium, by construc-
27 tion from individual marks in arrays. The printer in-
28 cludes at least one colorant-placing module for marking on
29 the medium.

30 It also includes a first sensor for determining
31 condition or relative positioning (or both) of the at
32 least one colorant-placing module; and in addition a

1 second sensor for making color measurements of marking
2 arrays formed on the medium by the at least one module.

3 In this document (including the claims), as noted
4 earlier the term "colorant" encompasses nonchromatic col-
5 orant; and the phrase "color measurements" encompasses
6 both densitometry and colorimetry. The phrase "relative
7 positioning" encompasses positioning of a single colorant-
8 placing module relative to its carriage or the printing
9 system generally, and also encompasses positioning of
10 plural colorant-placing modules relative to one another.
11 As will be clear, the first sensor may take the form of
12 separate sensors for determining condition and positioning
13 respectively.

14
15 The foregoing may constitute a description or defini-
16 tion of the first facet of the invention in its broadest
17 or most general form. Even in this general form, however,
18 it can be seen that this aspect of the invention signif-
19 icantly mitigates the difficulties left unresolved in the
20 art.

21 In particular, the invention provides a color-cali-
22 bration sensor that is distinct and separate from the
23 carriage-mounted sensor used for pen alignment, detection
24 of empty ink cartridges or inkdrop size, or identification
25 of malfunctioning nozzles. As a result the designer of a
26 printer is enabled to decouple the color-calibration sys-
27 tem design from the limitations of the carriage-mounted
28 pen alignment/status sensor.

29 In other words, it becomes possible to solve the
30 special problems of color calibration without insisting
31 upon compatibility of the two disparate sensing functions.
32 Detailed results of such less-restricted design will be
33 seen later in this document — but those further inventive

1 details in a certain sense flow from the innovation of
2 this first aspect of the invention.

3
4 Although this aspect of the invention in its broad
5 form thus represents a significant advance in the art, it
6 is preferably practiced in conjunction with certain other
7 features or characteristics that further enhance enjoyment
8 of overall benefits. For example preferably the second
9 sensor is for making colorimetric measurements.

10 It is also preferred that the printer additionally
11 include a colorant carriage — for scanning the at least
12 one colorant-placing module over the printing medium.
13 Also preferably the first sensor is mounted to the col-
14 orant carriage but the second sensor instead is mounted
15 independently of the first sensor.

16 In this case it is further preferred that the printer
17 ~~also include an auxiliary carriage for holding the second~~
18 ~~sensor and scanning the second sensor over such medium.~~
19 This auxiliary carriage in turn preferably is selectively
20 attachable to and detachable from the colorant carriage.

21 Another basic preference as to the first aspect of
22 the invention, in certain embodiments, is that the printer
23 include some means for excluding ambient light from the
24 second sensor during the making of color measurements.
25 For purposes of generality and breadth in discussion of
26 the invention, in the present document these means will be
27 called simply the "ambient-light excluding means".

28 Preferably these ambient-light excluding means
29 include a hood generally surrounding the second sensor
30 laterally with respect to a sensing direction, and a
31 mechanism for advancing the hood along the sensing direc-
32 tion toward the medium.

Still other preferences as to the first facet of the invention, in certain embodiments, are that the printer include a mechanism for advancing the second sensor into a measurement position — and a mechanism for advancing the second sensor into contact with the medium. In addition preferably the printer includes means for presenting at least one color reference target to the second sensor. Again for generality and breadth these means will be called, in this document, the "presenting means".

In preferred embodiments of a second of its main aspects, the invention is an incremental printer for forming desired images on a printing medium, by construction from individual marks in arrays. The printer includes at least one colorant-placing module for marking on the medium.

It also includes a first carriage for scanning the colorant-placing module over the medium. In addition it includes a second carriage, discrete from the first carriage, for use in refining the quality of images produced by the printer.

The foregoing may serve as a description or definition of the second facet of the invention in its broadest or most general form. Even in this general form, however, it can be seen that this aspect of the invention too significantly mitigates the difficulties left unresolved in the art.

In particular, in this facet of the invention the source of certain previously discussed limitations of the prior art is now localized in the scanning carriage. This is a major conceptual step from the summary of the preceding "Background" section of this document — which could only point in a much more abstract way to "time-consuming

1 and error-prone" colorimetry and "automated but fundamen-
2 tally inaccurate" pseudodensitometry.

3 As seen in the light of this second aspect of the
4 invention, what makes colorimetry or true densitometry
5 time consuming and error prone is its historical inaccess-
6 sibility to the already-available carriage (due to overly
7 bulky or heavy components used in colorimetry). What
8 makes pseudodensitometry fundamentally inaccurate is that
9 it is limited to what can be carried on the already-avail-
10 able carriage.

11 The second facet of the invention, now under discus-
12 sion, makes it possible to break out of this circular-
13 seeming conundrum. This is accomplished by providing two
14 separate and distinct carriages — once again to decouple
15 the requirements of color measurement from those of the
16 printing process itself, and from those of relatively
17 primitive pen-status or alignment systems.

18
19 Although this facet of the invention in its broad
20 form thus represents a significant advance in the art, it
21 is preferably practiced in conjunction with certain other
22 features or characteristics that further enhance enjoyment
23 of overall benefits. For example preferably the second
24 carriage is selectively attachable to and detachable from
25 the first carriage.

26 Also it is preferable that the second carriage scan a
27 sensor over the medium. In this case, still more prefera-
28 bly the sensor is a sensor for making color measurements
29 of marks formed on the medium by the at least one color-
30 ant-placing module — and preferably the second carriage
31 also holds at least one reference target for presentation
32 to the sensor. (Alternative mounting of targets station-

1 arily, to fixed components of the printer, will be taken
2 up shortly.)

3 As to the last-mentioned preference, the second car-
4 riage itself actually holds not only the sensor but also a
5 target for the sensor to view. This target may be made to
6 function as an absolute calibration standard — which
7 enables the system to escape from a previously discussed
8 handicap of automatic in-printer calibration, namely the
9 absence of an absolute standard. In this regard prefer-
10 ably the sensor is a colorimetric sensor, and the refer-
11 ence target is a colorimetric reference target.

12 Yet another preference is that the printer also
13 include a hood generally surrounding the sensor laterally
14 with respect to a sensing direction — and a mechanism for
15 advancing the hood along the sensing direction toward the
16 medium. It is also preferable that the printer include a
17 mechanism for advancing a component associated with the
18 sensor into contact with the medium.

19 Such a component, merely by way of example, might be
20 the hood or a compliant facing fixed to the hood. In ad-
21 dition this second facet of the invention is amenable to
22 other applications — as for instance a video camera or
23 the like mounted to the second carriage can usefully meas-
24 ure image-quality-related parameters other than color.

25
26 In preferred embodiments of a third basic aspect or
27 facet, the invention is an incremental printer for forming
28 desired images on a printing medium, by construction from
29 individual marks in arrays. The printer includes at least
30 one colorant-placing module for marking on the medium, and
31 a sensor for measuring color properties of colorant marked
32 on such medium by the colorant-placing module.

1 In addition the printer includes a hood for excluding
2 ambient light from the sensor during the color-property
3 measuring. The hood generally surrounds the sensor lat-
4 erally with respect to a sensing direction. In addition
5 the printer has a mechanism for automatically advancing
6 the hood along the sensing direction toward the medium.

7
8 The foregoing may constitute a description or defi-
9 nition of preferred embodiments of the third facet of the
10 invention in its broadest or most general form. Even in
11 this general form, however, it can be seen that this as-
12 pect of the invention significantly mitigates difficulties
13 left unresolved in the art.

14 In particular, the mechanism described is able to
15 minimize the admission of ambient light into the color-
16 measuring system — and to do so more effectively than is
17 possible by carrying an ambient-excluding hood always at
18 the same distance needed for effective clearance during
19 movement of the sensor into position.

20 Nevertheless, as before, for maximum enjoyment of the
21 benefits of the invention preferably certain additional
22 features or characteristics are included. For instance,
23 it is preferable that the hood-advancing mechanism also
24 automatically advance the color sensor into a measurement
25 position.

26 Also preferably the hood includes, at a forward sur-
27 face, a compliant material for facilitating an effective
28 contact between the hood and the printing medium. Another
29 preference is that the hood be movable with respect to the
30 sensor; and that the mechanism advance the hood with re-
31 spect to the sensor. For best exclusion of ambient light,
32 the hood (or its compliant facing) is advanced into con-
33 tact with the medium.

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1 Another preference is that the printer include a door
2 for protecting the sensor when not in use, and that the
3 hood-advancing mechanism also include some means for open-
4 ing the door for measurements by the sensor. Other pref-
5 erences as to the door will appear shortly.

6
7 In preferred embodiments of a fourth of its aspects,
8 the invention is an incremental printing system for form-
9 ing desired images on a printing medium. The printing
10 system forms the images by construction from very large
11 numbers of individual liquid-ink drops ejected onto such
12 medium in arrays. (Typical images modernly include many
13 thousands of drops per square centimeter.)

14 The printing system includes at least one colorant-
15 placing module for ejecting very large numbers of liquid-
16 ink drops onto the medium. This ejection occurs substan-
17 tially whenever the printing system is in use for forming
18 images.

19 Also included in the printing system is a sensor,
20 having at least one optical surface, for infrequently
21 measuring color properties of ink previously received on
22 the medium from the at least one colorant-placing module.
23 This measuring occurs substantially only when the printing
24 system is not in use for forming images.

25 The printing system further includes an automatic
26 microprocessor for using the measured color properties in
27 refining operation of the colorant-placing module. The
28 printing system uses these measured properties to optimize
29 the quality of images formed on the medium thereafter.

30 In addition the printing system includes a door for
31 protecting the at least one optical surface of the sensor
32 from being coated by atmospherically carried residual
33 liquid ink. This protection is provided when the sensor

1 is not in use — particularly including whenever the
2 printing system is in use for forming images.

3 Yet additionally included is a mechanism for automat-
4 ically opening the door before use of the sensor, and for
5 automatically closing the door after use of the sensor.
6 This mechanism enables the microprocessor to reliably op-
7 timize the quality of images, free from degradation of the
8 measured color properties by coating of liquid ink on the
9 at least one optical surface.

10
11 The foregoing may describe or define preferred embod-
12 iments of the fourth facet of the invention in its broad-
13 est or most general form. As will be understood, in this
14 printing system the microprocessor may be the general-
15 purpose processor in an associated computer, or can be a
16 programmed microprocessor in a printer product. (By that
17 is meant a printer case that includes the sensor, the col-
18 orant-placing module or modules, whatever mechanisms dis-
19 charge those modules and position them with respect to the
20 printing medium, and associated componentry).

21 If in the printer, the processor can take the form of
22 a general-purpose processor holding a program, or reading
23 program modules from an associated read-only memory (ROM);
24 or the processor may be an application-specific integrated
25 circuit (ASIC). Alternatively still, the processor can be
26 in another separate enclosure, e. g. a raster image pro-
27 cessor (RIP). Such RIP devices are available nowadays for
28 use with computer-controlled printers, to avoid tying up
29 either the computer or the printer.

30 This fourth aspect of the invention addresses and re-
31 solves the problems of the contaminated cover glass dis-
32 cussed earlier in the "Background" section. As will be
33 seen this facet of the invention can also be exploited in

1 connection with the lack of an absolute standard in some
2 color-measurement systems.

3 This aspect of the invention is preferably practiced
4 in conjunction with optimizing characteristics. For exam-
5 ple preferably the door-opening-and-closing mechanism aut-
6 omatically opens the door substantially in preparation for
7 use of the sensor; and also automatically closes the door
8 promptly after use of the sensor. In some embodiments the
9 door-opening mechanism moves the sensor into a measurement
10 position as well.

11 If the sensor has multiple optical surfaces, prefer-
12 ably the door protects all of them from being coated with
13 ink. Some embodiments may have two or more sensors —
14 e. g., a sensor for measuring color properties of the pre-
15 viously received ink; and a separate sensor for determin-
16 ing, from patterns of the previously received ink, condi-
17 tion of the at least one inkdrop-placing module.

18 Such condition may include whether the module is out
19 of ink. If there are plural placing modules, the separate
20 sensor may be for use in determining, from patterns of the
21 previously received ink, either the condition just de-
22 scribed, or relative positioning of the inkdrop-placing
23 modules — or both. This fourth facet of the invention,
24 however, is also applicable to printing systems in which a
25 single sensor is used for color measurement as well as the
26 condition or positioning determinations just discussed.

27 Also preferably this aspect of the invention includes
28 some means for measuring at least one absolute color ref-
29 erence, when the door is not open. (By "not open" is
30 meant that the door is not admitting color characteristics
31 of the previously received ink to the sensor.) For gener-
32 ality and breadth these means will be called the "abso-
33 lute-reference measuring means".

1 In this case it is further preferable that the abso-
2 lute-reference measuring means include at least one color
3 reference target that is exposed to the sensor when the
4 door is closed. When such a target is included, it is
5 preferably carried on a surface of the door.

6 Another preference is that the door take the form of
7 a shutter. In this case it is preferable that the shutter
8 be in a plane generally parallel to the printing medium,
9 and that the shutter slide open and shut generally within
10 that plane.

11
12 A fifth facet or aspect of the invention is, in its
13 preferred embodiments, an incremental printer for forming
14 desired images on a printing medium, by construction from
15 individual marks in arrays. The printer includes at least
16 one colorant-placing module for marking on the medium, and
17 a sensor for measuring color properties of colorant marked
18 on the medium by the colorant-placing module.

19 Also included is a flashlamp for illuminating
20 colorant marked on the medium at an intensity high enough
21 to make ambient light substantially insignificant to the
22 measuring process.

23
24 The foregoing may be a broad, general definition or
25 description of the fifth aspect of the invention. As will
26 be understood, this facet of the invention is particularly
27 valuable for its virtually complete elimination of any
28 need to shield the sensor from ambient light.

29 From the familiar use of flashlamps in photography it
30 is well known that such lamps are readily made bright
31 enough to essentially swamp out normal room illumination
32 and in many cases even moderate daylight. (This is not to
33 say that the sensor of this fifth facet of the invention

1 is necessarily intended for operation outdoors in direct
2 sunlight; the sensor can function well within a generally
3 conventional printer cabinet, with the usual minimal
4 shielding.)

5 Thus according to this aspect of the invention the
6 sensor requires no large hood, and no mechanism for ad-
7 vancing the sensor into or away from contact with the
8 print medium or the ink thereon. In fact the sensor
9 requires no mechanism for advancing the sensor along the
10 measurement direction at all.

11 Previous colorimeters using flashlamps — essentially
12 for the benefit of their spectral distribution, as men-
13 tioned earlier — have employed hoods and in general have
14 required manual advance of the hood along the measurement
15 direction and into contact with the medium bearing the
16 printed test pattern.

17 According to this facet of the invention, in compari-
18 son, a great simplification is effected, and with rela-
19 tively little handicap in terms of weight, bulk, or cost.
20 Some electronic complexity is added.

21 As this facet of the invention has minimal need for
22 shielding of the sensor against ambient light, preferred
23 characteristics and features for this facet of the inven-
24 tion in fact include minimal provision of such shielding.
25 Weight, bulk and cost benefits are thereby enhanced.

26 It is also preferable that, during the measuring, the
27 sensor is in contact with neither the medium nor colorant
28 marked on the medium. Mechanical simplification is there-
29 by optimized — and because of the brightness and result-
30 ing virtually complete elimination of ambient shielding,
31 the sensor is made and operated very differently from pre-
32 vious, handheld colorimeters fitted with flashlamps.

Another preference is that the flashlamp in fact operate in a flashing mode. In particular the lamp is best flashed for a time interval short enough to make energy consumption and heating by the flashlamp substantially insignificant.

A preferred embodiment of the invention in yet a sixth of its major facets or aspects is an incremental printer for forming desired images on a printing medium. The printer does so by construction from individual marks in arrays.

The printer includes at least one colorant-placing module for marking on such medium; and a sensor for measuring color properties of colorant marked on such medium by the colorant-placing module. In addition the printer includes a moving carriage for automatically positioning the sensor over colorant on such medium.

Further included is at least one reference target disposed for exposure to the sensor to provide a colorimetric reference measurement. This measurement is for use in conjunction with the measured color properties of colorant marked on the medium.

The foregoing may represent a description or definition of the sixth independent aspect or facet of the invention in its most general or broad form. Even in this form, however, it can be seen that this sixth facet of the invention importantly resolves troublesome difficulties of the art.

In particular, an absolute reference measurement can be obtained without going beyond the resources built into the printer. This expansion of resources enables automat-

ic operation of the reference measurement as well as the color-patch measurements discussed earlier.

Although the sixth facet of the invention as couched in its most general form thus importantly advances the art, it is nonetheless preferred to practice this aspect of the invention in conjunction with other features or characteristics that optimize the enjoyment of its benefits. For example, in one preferred form of this sixth facet of the invention preferably the at least one reference target is carried on the moving carriage.

In another preferred form, it is preferred that the at least one reference target be stationary, and the moving carriage comprise means for automatically positioning the sensor over the at least one reference target. In this case it is further preferred that the printer also include a shutter for protecting the at least one reference target, and some means actuated by the moving carriage for controlling the shutter.

In any event preferably the at least one target includes a white target. Also preferably the at least one target includes a black target. It is preferable too that the at least one reference target include one or more gray targets. Another preference is that the at least one reference target include a chromatically colored target.

The basis for these colorant preferences is well-established, for example in the Bockman and Borrell patent documents mentioned earlier. As those documents show, one of the most difficult colorimetric alignments for an incremental printer is producing accurate grays, and in particular gray-scale ramps; thus the nonchromatic references mentioned above are particularly useful.

Almost as demanding as this type of calibration, however, is the need for accurate presentation of fully

1 saturated primary colors — and close behind that consid-
2 eration is the accurate presentation of fully saturated
3 secondaries. In incremental printing, primary chromatic
4 inks are usually cyan, magenta and yellow — crosscombina-
5 tions of which are used to form the colors usually regar-
6 ded as primaries, namely red, green and blue (considered
7 secondary inks, for purposes of incremental printing).

8 Hence red, green and blue targets for comparison are
9 also very useful. When the system has difficulty approxi-
10 mating these as it should, a reason may be that the inks
11 loaded into the system pens are faulty or at least in some
12 way nonstandard, and this condition can be investigated
13 automatically if the system has accurate reference targets
14 for those colors as well.

15
16 All of the foregoing operational principles and
17 ~~advantages of the present invention will be more fully~~
18 appreciated upon consideration of the following detailed
19 description, with reference to the appended drawings, of
20 which:

21 22 23 BRIEF DESCRIPTION OF THE DRAWINGS

24
25 Fig. 1 is a perspective or isometric drawing, taken
26 from front left, of a representative large-format printer-
27 plotter that incorporates preferred embodiments of the
28 invention;

29 Fig. 2 is a like view, but enlarged and taken from
30 upper front right, of a sensor according to one preferred
31 embodiment of the invention — with the sensor seen in a
32 parked condition, and also showing portions of the car-
33 riage and platen system in the Fig. 1 printer — and also

1 illustrating a representative test pattern being printed
2 for later reading by a sensor according to the invention;

3 Fig. 3 is a like view, but less highly enlarged,
4 showing the Fig. 2 sensor in two different conditions
5 (parked, and coupled to the colorant carriage for color
6 measurements, respectively) with almost all of the Fig. 2
7 carriage system;

8 Fig. 4 is a like view but more highly enlarged and
9 taken from front above left, and showing the same sensor
10 decoupled from the colorant carriage;

11 Fig. 5 is a conceptual block-diagrammatic representa-
12 tion of a hardware system according to preferred embodi-
13 ments of the invention, with the sensor of Figs. 2 through
14 4 shown parked;

15 Fig. 6 is a like view but with the sensor coupled to
16 the colorant carriage;

17 Fig. 7 is a conceptual elevation, partly in cross-
18 section and very schematic, of a sensor according to pre-
19 ferred embodiments of the invention that ^{employs} ~~employ~~ a statio-
20 nary graded interference filter followed by an array of
21 detectors — shown in context with a representative print-
22 ing medium and test patch, and a representative micropro-
23 cessor — and shown with a sensor door open to expose the
24 working parts of the sensor to the test patch;

25 Fig. 8 is an elevation like Fig. 7 but with the door
26 closed to instead expose the working parts of the sensor
27 to a standard white reference target;

28 Fig. 9 is an elevation like Figs. 7 and 8 but with
29 the door moved to a third position in which the detector
30 stage of the sensor is substantially isolated from all
31 illumination;

1 Fig. 10 is an elevation like Fig. 7 but showing the
2 interference filter scanned and followed by a single
3 detector;

4 Fig. 11 is an elevation like Fig. 7 but showing a
5 sensor that uses a stationary diffraction grating instead
6 of a stationary interference filter; and

7 Fig. 12 is an elevation like Fig. 10 but showing a
8 sensor that uses a scanned diffraction grating instead of
9 a scanned interference filter;

10 Fig. 13 is an elevation like Figs. 10 and 12 but
11 showing a sensor that uses a rotating filter wheel instead
12 of a scanned interference filter or grating;

13 Fig. 14 is an elevation like Fig. 13 but showing a
14 sensor having two cases, nested and with the interior case
15 servodriven to equalize focal conditions as between exter-
16 nal test patch and internal reference target;

17 ~~Fig. 15 is a plan of a combination shutter and ref-~~
18 ~~erence target for use instead of the door in Figs. 6~~
19 ~~through 14;~~

20 Fig. 16 is an elevation like Fig. 13 but showing a
21 sensor that uses the Fig. 15 shutter/target and a telecen-
22 tric imager to equalize focal conditions between patch and
23 target;

24 Fig. 17 is an extremely schematic elevation of an-
25 other preferred embodiment in which the sensor is bodily
26 lowered toward the printing medium;

27 Fig. 18 is a like elevation of a variant of the Fig.
28 17 sensor mounting arrangement, particularly showing the
29 sensor suspended for compliant engagement with the print-
30 ing medium;

31 Figs. 19 through 21 are a sequence of like elevations
32 showing another variant in which the sensor of Figs. 16

1 through 18 is automatically capped when not lowered for
2 making measurements;

3 Fig. 19A is a like elevation, but greatly enlarged,
4 showing the region 19A-19A of Figs. 19-21;

5 Figs. 22 and 23 are another sequence of like eleva-
6 tions but showing another preferred embodiment in which a
7 hood or optical shield is lowered from the sensor case to-
8 ward or onto the printing medium while a pair of trapdoors
9 above the shield is raised;

10 Figs. 24 and 25 are like Figs. 22 and 23 except that
11 the doors are initially below the shield, and swung out of
12 the optical path as the shield descends;

13 Figs. 26 and 27 are like Figs. 24 and 25 except that
14 the doors take the form of shutters that slide laterally
15 out of the shield path;

16 Fig. 28 is an elevation, partially in section and
17 very schematic, of portions of still another preferred
18 embodiment incorporating a stationary reference color
19 target fixed at the right end of the Fig. 3 main carriage
20 assembly — together with a protective carriage-operated
21 sliding shutter (shown partway through its stroke, i. e.
22 partly open) for covering the reference target;

23 Fig. 29 is a plan of the Fig. 28 target in its shut-
24 ter assembly;

25 Fig. 30 is a like view of the target alone; and

26 Fig. 31 is a view like Fig. 28, but also showing the
27 main carriage and the sensor/carriage module, actuating
28 the protective shutter (through a greater part of its
29 stroke than in Fig. 28).

30
31

DETAILED DESCRIPTION
OF THE PREFERRED EMBODIMENTS

Two preferred embodiments of the present invention are believed to be the first incremental printing system to provide densitometric or full colorimetric self-calibration, as compared with limited pseudodensitometric color calibration available heretofore. Two alternative preferred embodiments are the first commercial incremental printing system to provide pseudodensitometric or densitometric color calibration that is protected against error due to coating of optical elements by ink aerosol.

Each of these embodiments represents a major step forward over the prior art. An objective is high-quality color sensing elements that enable the overall system to have fully characterized colorimetric or spectrometric performance. A color sensor that provides color data in three or more color bands allows construction of color tables for arbitrary printing media at the time of use, rather than at the time of design.

Such tables can take into account inkdrop size and other current variables as well as the printing medium. With such a system it is not necessary to construct tables at the factory and store those tables permanently.

1. SINGLE- AND DUAL-SENSOR EMBODIMENTS

(a) Most highly preferred embodiment — More specifically, the most favored embodiments of the present invention use a sensor excited by a high-intensity lamp that requires little or no detector shielding against ambient light. This most highly preferred sensor, when it is

1 fitted with a suitable optical coupler and wavelength-
2 selection unit, accordingly is considered sufficiently
3 lightweight and compact to incorporate into an otherwise
4 generally conventional pen-carriage assembly.

5 It is small enough to share the carriage with another,
6 more elementary sensor used to determine pen condition
7 or alignment. As will be understood, however, the preferred
8 sensor alternatively can be adapted to take over
9 the tasks of that other sensor as well.

10 ~~Key to achieving a sufficiently lightweight and compact~~
11 ~~colorimeter to avoid a separate carriage is minimizing~~
12 ~~the use of relatively heavy solenoid actuators, stepper~~
13 ~~motors, and the like. Most commercially available~~
14 ~~colorimeter models occupy some fifteen to thirty cubic~~
15 ~~centimeters and weigh over a hundred grams.~~

16 Thus it is particularly favorable to eliminate hinged
17 doors and translating hoods that are not only bulky and
18 possibly heavy but also require heavy actuators. A hood
19 can be avoided with a bright lamp, and shifting of the
20 colorimeter to equalize focal lengths as between color
21 swatches and target can be avoided with optics that minimize
22 sensitivity to focus.

23 If an electrically activated door is to be included,
24 both for optics protection and to facilitate provision of
25 an onboard reference target, a circular shutter system
26 seems preferable. Rotary sliding motion can be easily
27 geared down for actuation by a very small, lightweight
28 motor; yet actuation by motion of the carriage itself is
29 preferable.

30 Alternatively reference targets may be stationary
31 (that is to say, not onboard the pen or sensor carriage)
32 and accessed by the sensor through suitably controlled
33 movements of the moving carriage. Further elaboration of

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1 these several configurations appear in later subsections
2 of this document.

3
4 (b) Alternative preferred embodiments — A still-
5 highly-regarded alternative group of embodiments provides
6 dual carriages with respective sensors that can be opti-
7 mized independently for color and pen-management tasks.
8 When used with conventional, lower-intensity lamps the
9 color sensor here requires ambient-light exclusion.

10 This alternative calls for stopping the colorimeter
11 over each test patch in turn, and also calls for an ambi-
12 ent-light hood or the like — to be shifted down against
13 the print medium. The movement requires an actuator.

14 Nevertheless, these conditions are readily satisfied
15 without degrading print-stage performance, since the extra
16 weight and size of the shields is accommodated by severing
17 requirements of the color sensor from those of the pen-
18 condition/alignment sensor. This figurative decoupling of
19 the requirements is achieved by literally decoupling the
20 color-sensor carriage from the pen carriage — i. e., by
21 placing the color sensor on an auxiliary carriage.

22 The auxiliary carriage ideally is just a sled that
23 moves on the same support-and-guide surfaces as the pen
24 carriage, and is coupled to the pen carriage when use of
25 the color measuring system is desired. The sled is pushed
26 to one side and decoupled when calibration is complete.

27 This auxiliary carriage can have very loose require-
28 ments. As it is used only very infrequently its lifetime
29 as measured in duty cycles is very low. Its positioning
30 accuracy need be only sufficient to position the sensor
31 over a relatively large test patch.

32 As the pen carriage is only called upon to position
33 the sled during the color-calibration reading mode, the

1 sled need not be movable at high speed. Since it can
2 therefore be moved rather slowly, its weight and size are
3 not at all critical.

4 Electrical connections to the color sensor can be
5 made either through a connector at the coupling point
6 between the pen and color-sensor carriages, or through a
7 separate conventional umbilicus extending directly between
8 the color sensor and the printer electronics.

9
10 An auxiliary carriage is not necessarily restricted
11 to use with the relatively heavier color sensor that has
12 been under discussion. The sled can be used to carry the
13 previously introduced lightweight compact sensor instead.
14 This may be the arrangement of choice for various reasons
15 — including for example attainment of less than ideal
16 compactness or lightness in weight, or to incorporate
17 other functionalities on the auxiliary carriage.

18
19 Another alternative preferred embodiment is a sensor
20 with a door to protect optics from ink-aerosol. This em-
21 bodiment may be as modest as a pseudodensitometer that is
22 thus protected, substituted for color sensors shown below.

23
24 (c) The system — The invention is now most prefera-
25 bly implemented in a printer/plotter that includes a main
26 case 1 (Fig. 1) with a window 2, and a left-hand pod 3
27 that encloses one end of the chassis. Within that enclo-
28 sure are carriage-support and -drive mechanics and one end
29 of the printing-medium advance mechanism, as well as a
30 pen-refill station with supplemental ink cartridges.

31 The printer/plotter also includes a printing-medium
32 roll cover 4, and a receiving bin 5 for lengths or sheets
33 of printing medium on which images have been formed, and

which have been ejected from the machine. A bottom brace and storage shelf 6 spans the legs which support the two ends of the case 1.

Just above the print-medium cover 4 is an entry slot 7 for receipt of continuous lengths of printing medium 4. Also included are a lever 8 for control of the gripping of the print medium by the machine.

A front-panel display 11 and controls 12 are mounted in the skin of the right-hand pod 13. That pod encloses the right end of the carriage mechanics and of the medium advance mechanism, and also a printhead cleaning station. Near the bottom of the right-hand pod for readiest access is a standby switch 14.

Within the case 1 and pods 3, 13 a cylindrical platen 41 (Fig. 2) — driven by a motor 42, worm 43 and worm gear 44 under control of signals from a digital electronic processor — rotates to drive sheets or lengths of printing medium 4A in a medium-advance direction. Print medium 4A is thereby drawn out of the print-medium roll cover 4.

Meanwhile a pen-holding carriage assembly 20 carries pens back and forth across the printing medium, along a scanning track — perpendicular to the medium-advance direction — while the pens eject ink. The medium 4A thus receives inkdrops for formation of a desired image, and is ejected into the print-medium bin 5. As indicated in the drawing, the image may be a test pattern of numerous color patches or swatches 56, for reading by a color sensor to generate calibration data.

A small automatic optoelectronic sensor 51 rides with the pens on the carriage and is directed downward to obtain data about pen condition (nozzle firing volume and direction, and interpen alignment). In a printer with a simple pseudodensitometric or densitometric system, this

1 same sensor 51 may perform the necessary optical measure-
2 ments for the pseudodensitometry or densitometry too.

3
4 For present purposes, furthermore, the same sensor
5 case 51 also symbolizes a colorimetric sensor according to
6 the most highly preferred embodiments of the invention.
7 In such embodiments the colorimetric sensor can also be
8 used to perform the pen-function observations. Although
9 those embodiments, as mentioned above, are particularly
10 compact and lightweight, they do require a somewhat larger
11 sensor enclosure 51 than suggested in Fig. 2.

12 The other preferred embodiment of the present inven-
13 tion uses instead an auxiliary colorimeter carriage 52.
14 This carriage houses a colorimetric sensor that is dis-
15 tinct from the pen-function sensor 51 but can be secured
16 next to it by a coupling 55 — or decoupled for parking,
17 as illustrated, at the edge of the platen 41.

18
19 A very finely graduated encoder strip 36 is extended
20 taut along the scanning path of the carriage assembly 20
21 and read by another, very small automatic optoelectronic
22 sensor 37 to provide position and speed information 37B
23 for the microprocessor. One advantageous location for the
24 encoder strip 36 is immediately behind the pens.

25 A currently preferred position for the encoder strip
26 33 (Fig. 3), however, is near the rear of the pen-carriage
27 tray — remote from the space into which a user's hands
28 are inserted for servicing of the pen refill cartridges.
29 For either position, the sensor 37 is disposed with its
30 optical beam passing through orifices or transparent po-
31 rtions of a scale formed in the strip.

32 The pen-carriage assembly 20 is driven in reciproca-
33 tion by a motor 31 — along dual support and guide rails

1 32, 34 — through the intermediary of a drive belt 35.
2 The motor 31 is under the control of signals from the
3 digital processor.

4 Likewise the auxiliary, colorimeter carriage and en-
5 closure 52 — present only in the alternative embodiment
6 as explained above — rests on both rails 32, 34, whether
7 parked next to the right end bracket 39 of the scan assem-
8 bly or, if in use, coupled to the pen carriage 20 as shown
9 at 52'. (In Fig. 3 the callout for the colorimeter car-
10 riage/housing shown adjacent to the pen carriage 20 is
11 marked with a "prime" symbol thus, 52', to emphasize that
12 there is actually only one colorimeter carriage, not two
13 as might otherwise be supposed from the drawing.)

14 Those skilled in the art will now recognize that a
15 parking position next to the left end of the carriage
16 assembly is equally appropriate in the abstract. Ordinar-
17 ily practical considerations for any given product will
18 dictate which end is preferable.

19
20 Naturally the pen-carriage assembly includes bays 22
21 (Fig. 4) for pens — preferably four pens 23-26 holding
22 ink of four different colors respectively. Typically the
23 inks are yellow in the leftmost pen 23, then cyan 24, ma-
24 genta 25 and black 26.

25 Also included in the pen-carriage assembly 20 is a
26 rear tray carrying various electronics. The colorimeter
27 carriage too has a rear tray or extension 53 (Fig. 2),
28 with a step 54 to clear the drive cables 35.

29
30 In a block diagrammatic showing, the pen-carriage
31 assembly is represented separately at 20 (Fig. 5) when
32 traveling to the left 16 while discharging ink 18, and at
33 20' when traveling to the right 17 while discharging ink

1 19. It will be understood that both 20 and 20' represent
2 the same pen carriage.

3 The previously mentioned digital processor 91 pro-
4 vides control signals 20B to fire the pens with correct
5 timing, coordinated with platen drive control signals 42A
6 to the platen motor 42, and carriage drive control signals
7 31A to the carriage drive motor 31. The processor 91
8 develops these carriage drive signals 31A based partly
9 upon information about the carriage speed and position
10 derived from the encoder signals 37B provided by the
11 encoder 37.

12 (In the block diagram all illustrated signals are
13 flowing from left to right except the information 37B fed
14 back from the sensor — as indicated by the associated
15 leftward arrow.) The codestrip 33 thus enables formation
16 of color inkdrops at ultrahigh precision during scanning
17 of the carriage assembly 20 in each direction — i. e.,
18 either left to right (forward 20') or right to left (back
19 20).

20 As the block diagram suggests, the auxiliary sensor
21 or colorimeter carriage 52 remains decoupled from the pen
22 carriage 20 and parked at right regardless of pen-carriage
23 direction, in the writing mode of Fig. 5. This includes
24 writing test pattern color patches 56 such as noted ear-
25 lier in Fig. 2.

26
27 In colorimetric-data reading mode, however — that
28 is, when reading those same patches 56, the pens are
29 turned off and the pen carriage moves next to the auxil-
30 iary sensor carriage 52' (Fig. 6) and the two are then
31 coupled together. The pen carriage and its drive and
32 position/speed-monitoring subsystems can then be brought

1 to bear in positioning the colorimeter carriage, and the
2 two carriages move together.

3 While the pens remain turned off, as indicated in
4 this second block diagram the pen carriage moves 16 the
5 auxiliary carriage, relatively slowly, from its parked
6 position to positions above all the patches 56 in turn.
7 This requires coordination with position of the platen 41
8 and printing medium 4A, to reach the several rows of pat-
9 ches (Fig. 2).

10 Depending on the order in which the patches are read,
11 the carriages may be called upon to reciprocate during the
12 reading mode. When the reading is complete for all rows,
13 the pen carriage moves 17 the colorimeter carriage back to
14 its parking position at the right.

15 16 17 2. SENSOR GEOMETRY

18
19 Alternative internal structures of the auxiliary col-
20 or-sensor assembly 52 appear in Figs. 7 through 16. Figs.
21 15 and 16 show the internal structure that is best adapted
22 to serve in a single-carriage system as the sensor 51.

23 As seen in Figs. 7 through 14, the color-sensor as-
24 sembly 52 has a coupling 55 for engagement with the pen
25 carriage. In the drawings this coupling is shown generi-
26 cally as it can take any number of different forms — for
27 example, most preferably a latch that is operated by rela-
28 tive movement of the carriages. Other choices include an
29 electromagnet that engages a ferromagnetic surface on the
30 pen carriage, or a solenoid-operated latch, or a self-mak-
31 ing passive latch that is solenoid broken.

32 A power supply 71 (Fig. 7) is onboard the auxiliary
33 carriage to power a flashlamp 72. Relatively high voltage

1 is required to start such a gas-discharge lamp, although
2 as is well known the voltage drops to quite low values
3 once the arc is struck.

4 Gas constituency and pressure, electrode geometry,
5 and to an extent even characteristics of the envelope es-
6 tablish the brightness, spectral properties, temperature,
7 life and specific electrical characteristic of a flash-
8 lamp. The firing waveform in turn participates in con-
9 trolling all those same properties.

10 If a different type of light source is used, then
11 generally a high-voltage source is not required. In that
12 case the power supply 71 may be consolidated with the rest
13 of the printer power supply.

14 Light 73 from the lamp is advantageously collected by
15 a collimator 74 for direction as a beam 76 through the
16 open port or doorway 61 to a test swatch 56 on the print-
17 ing medium 4A. ~~Good diffuse-reflectance measurement geom-~~
18 etries and protocols should be observed, in collecting the
19 reflected beam 76 through a field lens 82.

20 In particular, each swatch 56 scatters much of the
21 incident beam 75 into a wide solid angle, and reflects the
22 balance specularly at an exit angle equal to the angle of
23 incidence. The proportions depend upon the reflectance
24 properties of the ink and media.

25 The lens 82 should collect a representative sampling
26 of the scattered light, rather than a specularly reflected
27 sample of the source beam. Accordingly for good diffuse-
28 reflectance measurements ideally one or the other of the
29 two beams (incident and collected) is perpendicular to the
30 sample, while the other beam ideally is at forty-five de-
31 grees to both the perpendicular and the sample.

32 The illustrated geometry is one of those two options,
33 and those skilled in the art will recognize that the other

option can be substituted straightforwardly. Both forms render the sensor advantageously unresponsive to specular reflection, thus indicating more about the character of the test samples than of the source lamp.

The source stage 71-75 is partially isolated from the detection stage 76, 82-86 by a central baffle 81, to reduce stray light in the detection stage. At this point the brightness of the flashlamp is no aid, since the brightness of any stray light is proportional to the lamp brightness.

The field lens 82 may be selected to focus the swatch 56 onto a detector array 85 — through a wavelength-selecting device such as a graded (tapered) interference filter 84. Alternatively it may be desired to defocus the swatch relative to the detector array, in an effort to minimize systematic error in apparent spectral response that may arise from inadvertently correlating illumination patterns at the swatch with specific detectors in the array.

Generally philosophies of such optical relationships between the detector array 85 and other elements of the system are a matter of optics theory and outside the scope of this document, but in any event are straightforwardly managed by optics designers or engineers. One feature of the collection stage that is within the scope of the present discussion is the door 62, which if present is necessarily hinged 63 up out of the way of the beam 76.

Light of various wavelengths is selected by the thickness of the graded interference filter 84 that is respectively adjacent each detector 85 in the array. These wavelengths accordingly reach the corresponding detectors 85, producing in the detectors wavelength-vary-

1 ing electrical signals for passage via a bus 86 to the
2 microprocessor 91.

3 Depending on the particular color swatch, the signals
4 represent particular proportions of the different optical
5 wavelengths, which the processor 91 is able to interpret
6 in terms of human perceptual responses. In this way the
7 system can construct color tables for the particular com-
8 bination of inks in use and printing medium 4A in use.

9
10 In that process, however, as noted earlier it is ex-
11 tremely desirable to make adjustment for known absolute
12 color values. One such value is an ideal white, which can
13 be approximated with a magnesium oxide or equivalent ref-
14 erence target 64.

15 By hinging 65 the door 62 down — into position (Fig.
16 8) for protecting all the optical surfaces 72, 74, 82, 84,
17 85 — the system also exposes the same detector array 85,
18 through the same field lens 82, to the white reference
19 target 64 on the back of the door 62. The reference
20 target is now illuminated by the same light beam 75 that
21 previously illuminated the test swatch.

22 Now, however, not only the focal and illumination
23 distances but also the angles subtended by the beam on the
24 reference target are different from the distances and
25 angles which obtained with the door open. Furthermore the
26 distances and therefore angles to and from the color
27 swatch outside the port 61 are not perfectly controlled.

28 On the other hand, fortunately the geometry of the
29 system with the door closed is very well defined. There-
30 fore with care it is possible to make an arithmetic ad-
31 justment to take these differences into account with
32 reasonable accuracy, in deriving an excellent approxima-
33 tion to an absolute white reference reading.

1 As to the problem of ink aerosol coating the sensor
2 optics, no ink is ejected during the reading of color
3 swatches. It is true that some ink aerosol may remain in
4 the atmosphere immediately after the test patterns have
5 been printed, and some of this atmosphere is admitted to
6 the interior of the sensor chambers during the brief time
7 when the door is then opened.

8 This aerosol may coat the sensor optics. Quantita-
9 tively, however, this coating is negligibly tiny in com-
10 parison with what is deposited on the unshielded prior-art
11 cover glass. The procedure may be rendered even more re-
12 motely negligible by interposition of a brief delay be-
13 tween printing and reading of the test patterns.

14
15 Another desirable absolute reference reading would be
16 a reading taken with a dead-black target. The door 62 can
17 provide another kind of approximation to this second type
18 of absolute reference — namely a dark-current reading.

19 With the lamp turned off so that it emits no light
20 73" (Fig. 9), and with the door blocking substantially all
21 ambient illumination from reaching the detector array,
22 illumination 83" at the detectors is essentially nil.

23 Again, a dark-current reading is not the same thing
24 as a black-target reading with the same illumination as
25 used on the reference white target and on the test
26 swatches. Nevertheless, with careful preparation it is
27 possible to establish necessary relationships between the
28 two kinds of readings, and thereby to develop an excellent
29 approximation to an absolute black reference reading.

30 It will be noted that the Fig. 8 position of the door
31 62 is very nearly as good for this purpose as the Fig. 9
32 position, so that in practice the lower, Fig. 8 configura-
33 tion too should deliver a good black reference — but of

1 course again with the lamp turned off. If the door is
2 better sealed in its Fig. 8 position, then the lower
3 position may actually be better.

4
5 More reliability may result from using a single
6 detector 185 (Fig. 10), and scanning the wavelengths onto
7 that single detector. (In Figs. 10 through 13 the callout
8 numbers correspond to those in Fig. 7, except for the use
9 of prefix numbers in the hundreds place to call attention
10 to the varied features.)

11 Synchronization signals 192 are required to coordi-
12 nate the light pulses of the flashlamp with the wavelength
13 drive 184-189 and with the interpretive steps in the
14 processor 191 — and these three sets of signals are
15 delivered 193-195 as shown. In this case the bearing 187,
16 screw drive 188, guideways (not shown) and motor 189 may
17 weigh more than the several detectors 85 in Figs. 7
18 through 9, but with the auxiliary-carriage configuration
19 the extra weight is insignificant.

20 Better optical efficiency and therefore overall sig-
21 nal-to-noise ratio may be available with an inexpensive
22 cast diffraction grating 284 (Fig. 11) illuminating an
23 array of detectors 285. In this system an auxiliary
24 baffle 281' in conjunction with the door helps avoid
25 crosstalk from unwanted orders of the grating, as well as
26 further screening stray light from the lamp stage out of
27 the detection stage 283'-285.

28 Combining this consideration with the reliability of
29 a scanning system as in Fig. 10, leads to a scanning
30 grating color sensor — in which the grating is mounted to
31 a table 387 (Fig. 12). The table rotates about an axis
32 (not marked) that is parallel to the grating lines, pass-
33 ing through the face of the grate near its center.

1 A worm gear 387', formed in or fixed to the edge of
2 the rotary table, is driven by a motor 389 through a worm
3 388. As in the scanning-filter embodiment, synch signals
4 392 are provided at 393 to the lamp supply, at 394 to the
5 grating drive motor 389, and at 395 to the processor. The
6 processor provides an electronic grating cam.

7 Yet another acceptable substitution is a rotating
8 filter wheel 484 (Fig. 13) and drive motor 489. These
9 take the place of the scanning filter or grating.

10 In the systems of Figs. 7 through 13, as mentioned
11 earlier, the different elevation of the reference white
12 target 64 (Fig. 8) relative to the target patches 56 may
13 give rise to some irregularities in calibration. One ap-
14 proach to removing this drawback is to lower the color-
15 sensing stage relative to the platen when measuring the
16 color patches, and raise that stage for measurements of
17 the reference target.

18 Such movement can be effected by, for example, subdi-
19 viding the enclosure of the color sensor into an outer
20 shell 552 and an inner housing 552', and providing a motor
21 515 and screw drive 516 for controlling the vertical posi-
22 tion of the inner housing 552' relative to the outer
23 housing 552.

24
25 A different way of approaching the focal problem is
26 illustrated in Figs. 15 and 16, together with a rotating-
27 shutter type of door. These drawings include no coupling
28 for engagement with the pen carriage, as this system is
29 light and compact enough to ride directly on that carriage
30 as previously mentioned. Nevertheless if preferred the
31 system of Figs. 15 and 16 can be provided with a coupling
32 and implemented as an auxiliary sensor/carriage like those
33 of Figs. 7 through 14.

1 Here the shutter 562 has three sectors — one refer-
2 ence white 564, one reference black 562' and the third an
3 aperture 561. For reasons discussed elsewhere in this
4 document, although Fig. 15 illustrates just two targets
5 the shutter may be provided instead with as many as ten
6 discrete reference targets, or even more.

7 The shutter is oriented horizontally and is operated
8 about a vertical pin 663, fixed in the floor of the color-
9 sensor housing 652, by a motor 617. The shutter need not
10 turn at all quickly and so may be geared down and driven
11 by an ordinary d. c. motor 617.

12 The shutter may be stopped at positions determined by
13 economical encoders (not shown) on the rim — or prefera-
14 bly found by interpreting the return light signals at the
15 main detector 685, and in particular interpolating between
16 the signals from the centers of the dead-black and pure-
17 white targets.

18 The flashlamp 672 in this case is made roughly circu-
19 lar, and encircles a frustoconical baffle 681 that depends
20 from a horizontal central bulkhead 652'. Due to the dif-
21 ference in illumination distances, the illumination 675 at
22 the color swatch is not as bright as that at the reference
23 targets.

24 Collection distances, however, are rendered rela-
25 tively unimportant through use of a telecentric imager 682
26 described in the above-mentioned patent document of
27 Schmidt. Though originally conceived for use in a swath
28 scanner, the imager 682 with routine modification is
29 adaptable for the purpose shown.

30 As shown here and by Schmidt the imager is a unitary
31 cast solid element with the four reflecting surface areas
32 aluminized or silvered. The collected light 676 enters

1 the cast imager at lower right, and after four internal
2 reflections exits rightward.

3 From the imager, the beam passes to the detector 685,
4 through a spinning filter wheel 684 or other wavelength-
5 selection element such as shown in Figs. 7 through 12.
6 The Schmidt document also shows variant forms in which the
7 reflectors are conventionally formed and mounted discrete
8 mirrors.

9 Arithmetic compensation for the illumination incon-
10 sistency mentioned above is desirable. It can be worked
11 out empirically, to provide an approximation for the
12 absolute reference points which is somewhat better than
13 that for the embodiments of Figs. 8 through 14.

14 This is particularly true because collection of the
15 reflected beam is considerably better controlled in the
16 Fig. 16 case. As the drawing suggests, careful design of
17 the baffle 681 can be made to partially screen the targets
18 from the lamp, and thereby partly equalize the illumina-
19 tion on the targets with that on the swatches.

20 21 22 23 3. SENSOR AND HOOD MOUNTING FOR AMBIENT-LIGHT EXCLUSION

24
25 Absent an adequately bright flashlamp, the alterna-
26 tive solution to the ambient-light problem is mechanical.
27 The colorimeter carriage board 721 (Fig. 17) is stopped
28 over each test patch, and then an actuator 715, 716 pushes
29 the color-sensor assembly 752 down against the printing
30 medium.

31 The vertical motion can be achieved with an actuator
32 formed as, for instance, a rack 716 and pinion 715. The

1 mechanism should be biased with a spring 717 or the like
2 to allow for height variations.

3
4 As before, a mechanical solution is also available
5 for the problem of ink aerosol — a cap 853 (Figs. 19
6 through 21), door 953, 1053 (Figs. 22 through 25) or
7 shutter 1153 (Figs. 26 and 27) that hinges or slides open
8 either when commanded or through operation of a linkage
9 854 (Figs. 19 through 21) each time the sensor is lowered
10 against the media. When used in making a measurement the
11 optical elements inside the sensor 852 are exposed (Fig.
12 19) through its bottom orifice, which contacts the print-
13 ing medium 4A.

14 As an example with regard to the linkage 854, when
15 measurement is complete the support shaft 816 is raised
16 (as by a rack-and-pinion 715, 716, Fig. 17), lifting the
17 ~~sensor 852 from the medium 4A (Fig. 20).~~ Fixed to and
18 rising with the support shaft 816 is a slide-pin 856 (Fig.
19 19A), which in turn raises the slot 857 formed in the
20 upper right corner of the link 854.

21 Upward motion of the slot cooperates with the fixed
22 pivot 855 (Figs. 19 through 21) to force the link 854 into
23 counterclockwise rotation (Fig. 20). This rotation car-
24 ries the cap 853 around under the sensor orifice and then
25 upward relative to the sensor 852 until the orifice is
26 covered (Fig. 21).

27 By virtue of the trigonometric properties of the
28 slot-and-pin fitting 856-857 relative to the fixed pivot
29 855, the cap 853 at first rises more slowly than the
30 sensor 852, until the sensor is well clear of the printing
31 medium and also clear of the cap 853. Then the cap rises
32 more quickly, to catch up with and close the orifice.

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1 Various mechanisms that accomplish these tasks with
2 varying degrees of effectiveness include clamshell doors
3 (not shown) that open to form a partial hood. Also inclu-
4 ded are trapdoors 1053 that are opened by lowering of a
5 tube-shaped hood 1081 against the print medium.

6 A soft material can be used as the nose 982 of the
7 sensor hood or tube 981 (Fig. 23) to allow it to conform
8 to the print medium thoroughly; and trapdoors 953 may be
9 above rather than below the tube 981. Also included are
10 rotary shutters as in Fig. 16, which as before may include
11 reference targets. If the system is sensitive to focal
12 distances, separate provision must be made for stopping
13 the sensor assembly at the correct height.

14 As noted in relation to the illustrations considered
15 earlier, no printing takes place while the swatches are
16 being read. Some ink aerosol may remain in the ambient
17 after printing of the test patterns, and this aerosol may
18 coat the optical elements during the brief period of the
19 swatch-reading mode — but this effect is minuscule com-
20 pared with the amount deposited during a year of printing
21 as in the cover-glass system of the prior art.

22 The door or shutter is operated by a separate actua-
23 tor, or by motion of the carriage against a stop that in
24 turn presses against an on/off trigger (a straightforward
25 adaptation of the following discussion of stationary tar-
26 gets), or is incorporated in the up-and-down actuator so
27 that moving the sensor down causes the door to open
28 through a simple linkage.

29
30 Another mechanical solution for a reference target is
31 to place a piece of material 1262' (Figs. 28 through 31),
32 such as magnesium oxide for example, next to the service
33 station of the printer — i. e., next to the carriage-

1 assembly right end bracket 39. Preferably the target is
2 directly under the color sensor 1252 in the service posi-
3 tion, and is at the height of the media 4A (Fig. 2) in the
4 print zone.

5 Note that the sensor/carriage assembly 1252 (Fig. 31)
6 for this purpose is advantageously a variant configured so
7 that at least the sensor extends beyond the bracket 39 and
8 over the target 1262'. This configuration can be provided
9 by stepping and extending either the pen carriage 20, as
10 shown, or preferably the auxiliary sensor carriage — in
11 an embodiment that includes such an auxiliary carriage.

12 The sensor can then take an absolute reading for this
13 white reference. In this event there is no focal-distance
14 or illumination-distance error.

15 When not in use, the target 1262' is covered by a
16 shutter 1262. In this way the reference too is protected
17 from ink aerosol.

18 In Fig. 29 the target surface 1262' is visible, just
19 to the left of the shutter 1262, 1203. The shutter pref-
20 erably has a drive plate 1203 that is pushed back by the
21 sensor 1252, as the sensor enters the service station —
22 so that no separate electrical actuator is needed.

23 Preferably this mechanical configuration is used to
24 provide not just one target 1262' but others including for
25 example a black target 1264, at least one neutral gray
26 target 1265 and one or more other targets 1266 if desired.
27 It has been explained earlier that it is extremely advan-
28 tageous to provide plural gray targets for testing a neu-
29 tral-gray ramp as constructed from chromatic inks — and
30 chromatic targets too for calibration of, e. g., three
31 saturated primary colors (secondary inks) and three sec-
32 ondary colors (primary inks). A desired total thus comes
33 to ten or more targets.

1 In Fig. 29 such additional targets 1264-1266 are con-
2 cealed by the shutter as indicated by presentation of the
3 leadlines in the broken line. (Targets are likewise indi-
4 cated in Figs. 28 and 31, as all the targets are concealed
5 within the frame 1201.)

6 Positioning of both the sensor and the shutter for
7 measurement of one or ten targets — or any intermediate
8 number, or even more — is equally straightforward once
9 the basic illustrated apparatus is provided. The system
10 processor must be suitably coordinated with the particular
11 target array that is physically positioned in the frame.

12 The shutter is biased 1204 toward its closed posi-
13 tion, away from the end plate 1205 of the target frame.
14 Lateral edges of the shutter slide in conventional tracks
15 (not shown) formed in the frame 1201, and a slot 1206 in
16 the end plate 1205 allows the shutter to slide out to
17 uncover the target as illustrated. The target-and-shutter
18 assembly 1201, 1203-1206 is either formed with or fastened
19 1202 to the main carriage-assembly bracket 39.

20
21 Another mechanical solution for one or more reference
22 targets is to place it or them on the inside of a shutter
23 or door as in Figs. 15 and 16 so that each such target can
24 be exposed to the colorimeter detector when the door is
25 closed. Being on the inside surface of the shutter, each
26 such target is shielded from aerosol when the shutter is
27 closed.

28 The foregoing discussion of Figs. 28 through 31 shows
29 that a stationarily mounted door or shutter is very easily
30 arranged for actuation by a moving carriage 1252. In the
31 configuration illustrated and discussed, the shutter and
32 target are fixed to the printer case or to a stationary
33 feature of the carriage assembly (e. g. bracket 39, Fig.

3), and it is a shutter-actuating component of the carriage (e. g., the sensor/carriage 1252 itself) that moves.

It will be entirely clear to those skilled in the art how to straightforwardly adapt such mechanisms for the converse case — i. e., a moving shutter and target actuated by a stationary component of the printer case or of the bracket 39. Such a mechanical arrangement is readily integrated into the configurations shown in any of Figs. 5 through 16, or Figs. 22 through 27. In addition it will be understood that the mechanisms of Figs. 17 through 21 are similarly actuated by action of the carriage 721 against a stationary stop.

The invention is not restricted to thermal-inkjet technology, or to any specific number of colors of ink. Major features are applicable to any printer that creates color effects by depositing dots on printing media; and the invention can be extended to any number of inks of arbitrary colors. As will be recognized by those skilled in the art, particularly with further guidance by the previously mentioned Borrell and Bockman documents, the desired number and character of reference targets may vary accordingly.

In the body of each apparatus claim the word "such" is used as a definite article in lieu of "the" or "said" when referring back to features that are introduced in preamble and are not parts of the invention. This convention is used exclusively, and consistently, with elements of the context or environment of the invention — as distinguished from elements of the claimed invention itself. The purpose is to make the claim more specific and defi-

1 nite, to more distinctly claim and particularly point out
2 what is the claimed invention and what is its context.

3

4 The above disclosure is intended as merely exemplary,
5 and not to limit the scope of the invention — which is to
6 be determined by reference to the appended claims.

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